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On the full scale and model scale cavitation comparisons of a Deep-V catamaran research vessel

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ABSTRACT
In pushing for greener ships and more sustainable operations, designers and researchers are being challenged to increase vessel performance whilst reducing environmental impact. One topical, and a somewhat challenging aspect of this pursuit, is the reduction in Underwater Radiated Noise (URN). There are several European Collaborative Research Projects currently underway that aim to outline a framework for noise standards, amongst these projects is the Seventh Framework Project (FP7) "Suppression of Underwater Noise Induced by Cavitation" (SONIC) that has been tasked with concentrating on the URN from propeller cavitation; the main contributor to underwater noise generation. As one of the participants of the SONIC project the Newcastle University was involved in the full-scale trials and model-scale propeller testing campaign. The full-scale trial conducted on board Newcastle University's catamaran research vessel R/V The Princess Royal involved cavitation observations though the dedicated observation windows above each propeller, Propeller Excited Vibration measurements as well as the off-board URN measurements. The model scale tests were made in *The Emerson Cavitation Tunnel* using a 1:3.5 scale dummy model of the starboard side demi-hull of the vessel. These tests tried to emulate, as best as possible, the full-scale trials in terms of measurement locations and viewing angles.

INTRODUCTION
There has been a growing interest in the underwater radiated noise from shipping in the recent years due to the call made by international organizations and rising environmental awareness(Atlar & Vasiljev, 2011; IMO, 2011). These calls and increasing concerns initiated some EU Projects. Within this frame work namely two projects SONIC and AQUO has started synchronously.

As a partner of the SONIC project UNEW has involved in various full scale and model scale experimental campaigns. The committed experiments have been conducted both on board of the UNEW's RV The Princess Royal and the Dummy model. This paper investigates the cavitation model tests of the Princess royal, including comparisons with full scale measurements.

The first section of the paper describes the experimental facility and the setup for the experiment, which will includes an overview of the cavitation tunnel (1.1), setup of the dummy hull (1.2), the torque identity (1.3) the Princess Royal Setup (1.4) and the camera setup (1.5). Section 2 describes the operating conditions and test matrix; Section 3 describes the full scale test observations; the results are compared with full-scale results after applying the scaling procedures in section 4; Section 5 discusses the results and conclusions are given in Section 6.

1 EXPERIMENT SETUP
To conduct the research into full-scale cavitation observation correlations two University facilities were used: the Emerson Cavitation Tunnel and the University Catamaran Research Vessel "The Princess Royal". The experiment involved the installation and development of a dummy hull including wake simulation and the photography of both the vessel and the model over a range of challenging conditions.

1.1 CAVITATION TUNNEL
The model scale tests were conducted in the Emerson Cavitation Tunnel (ECT) at Newcastle University in the UK. The facility is a closed circuit depressurised tunnel which has a measuring section of 3.2m x 1.2m x 0.8m; a contraction ratio of 4.274:1 and is therefore considered a medium sized facility.

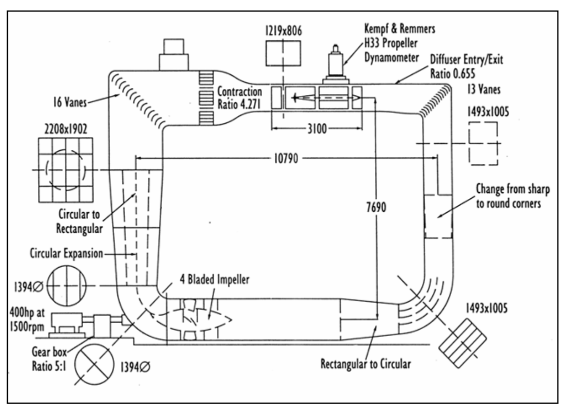

Figure 1: Emerson Cavitation Tunnel

The main dynamometer used in the tests was a Kempf & Remmers R45 dynamometer rated at 600 N Thrust and 15 Nm Torque. Figure 1 gives a general view of the tunnel circuit and Table *1* gives the basic specification for the ECT. More detailed information about the tunnel and the test facilities can be found in Atlar (2011).

Table 1: ECT Specifications

Facility type	Vertical, closed Circulating
Test section	3.10m x 1.22m x 0.81m
Contraction ratio	4.271
Drive system	4 Blade axial impeller
Main pump power	300 kW
Impeller diameter	1.4 m
Maximum velocity	8 m/s (15.5 knots)
Cavitation numbers	0.5 (min) to 23 (max)

To measure the performance of the propeller, open water tests at several vacuum conditions were conducted. The tests were performed to cover a practical range of advance coefficient (*J*) varying between *J* = 0.30 and *J* = 0.95 under normal atmospheric conditions. For the tests the tunnel water speeds were held at 3.0 m/s and 4.0 m/s, whilst the rotational rate of the propeller was varied to cover the above range of J values. Finally the data was non-dimensionalized using standard ITTC test procedures. The equations used in the analysis for the advance coefficient (J), thrust coefficient (K_T), torque coefficient, (K_Q), open water efficiency (η_o), the rotational cavitation number (σ_n) and the Reynolds Number (R_e), are given in Equations 1 ~ 6.

$$J = \frac{V}{nD} \tag{1}$$

$$K_T = \frac{T}{\rho n^2 D^4} \tag{2}$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \tag{3}$$

$$\eta_o = \frac{K_T}{K_Q} \times \frac{J}{2\pi} \tag{4}$$

$$\sigma_n = \frac{P_a + \rho g h_s - P_v}{0.5\rho(\pi n D)^2} \tag{5}$$

$$R_e = \frac{C_{0.7R}\sqrt{V^2 + (0.7\pi n D)^2}}{\nu} \tag{6}$$

Where: V is the tunnel free stream water velocity (m/s), n is the rotational speed of the propeller (rps), T is thrust (N) of the propeller, Q is the torque (N-m) of the propeller, ρ is the density of the tunnel solution (kg/m^3), σ_n is the rotational cavitation number, P_A is the atmospheric pressure in Pa, h_s is the shaft immersion of the propeller in m, P_v is the vapour pressure in Pa, $C_{0.7R}$ is the chord length at 0.7 Radius and ν is the kinematic viscosity of water (m^2/s).

The calculated non-dimensional numbers ensure that the conditions that the vessel is running at full-scale are properly represented in cavitation tunnel tests. Due to the inherent nature of a cavitation tunnel, the Froude number is not represented due to the lack of free surface in the tunnel testing conditions. In addition the rotational cavitation number is also calculated which is used due to the non-uniform flow velocity at the propeller plane.

The model tests for this experiment differ to conventional open water tests, due to the presence of a hull in the measuring section. This setup is reviewed in the next section however it is noted that for the current tests the torque is read from the propeller shaft to calculate the torque coefficient, which is then used to determine the torque value to match during the tests, known as torque identity.

Finally, during the whole course of the testing, the water quality of the facility has to be monitored with the application of the tunnel degassing procedures (Aktas & Korkut, 2013).

1.2 DUMMY MODEL SETUP

To accurately simulate the flow to the propeller in a cavitation tunnel a 'Dummy model' is often used to scale the full-scale condition. The dummy model has the advantage of simulating the tangential flow to the propeller plane. This ensures that the tangential components of the flow to the propeller plane are also represented in model scale. In order to adopt this method parallel section shown below has been shortened in accordance with ITTC procedures. (ITTC, 2011a, 2011b).

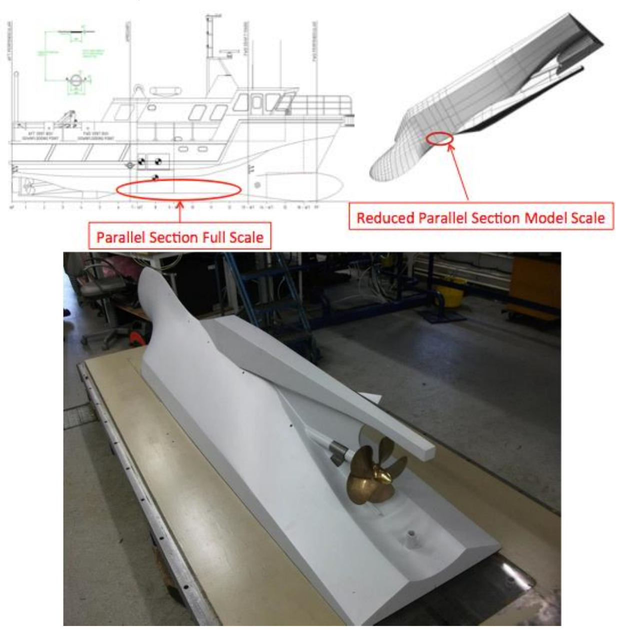

Figure 2: Dummy-Hull Philosophy

The initial and most important consideration for a dummy hull is the size of the model since it covers a variety of factors that has effect on various stages of the experimental campaign (Bark & W. B. van, 1978). The factors include the model scale, the facility size limitations, dynamometer and sensor limitations and ITTC guidelines for maximum blockage of tunnel cross section

The full-scale vessel should be initially scaled down by the experiment scaling factor. Then the length of the parallel section of the vessel, which is considered to have relatively less impact on the inflow to the propeller, is reduced. The shortening should be done with caution since the main hull lines should not be interrupted during the process. A final check should also be made to ensure the space requirements for the drive train. The general specification of the hull model used during experiments and its comparison with the general particulars of the full-scale vessel are given in Table 2.

Table 2: Full-scale & model scale Particulars

	Full scale	Model scale
Length overall (m)	18.88	3.007
Length between perpendiculars (m)	16.45	N/A
Length of waterline (m)	16.45	N/A
Beam, moulded (m)	7.3	0.56
Draft at fwd perpendicular (m)	1.75	0.57
Draft at aft perpendicular (m)	1.85	0.495

A right-handed propeller with a diameter of 0.214m was used for the model test and this was modelled in the starboard side demi-hull. The data for the full scale and model propeller is given in Table 3 as well as the model propellers as in Figure 3.

Table 3: Propeller Characteristics

	Ship	Model
Diameter D (m)	0.75	0.214
Blades, Z	2	2
Pitch Ratio at 0.7R	1.057	1.057
Chord Length at 0.7R, [m]	0.352	0.1006
Skew Angle [Deg]	19°	19°
Rake Angle [Deg]	0°	0°
Expanded Blade Area Ratio	1.057	1.057
Boss Diameter Ratio	0.2	0.2
Scale ratio, λ	3.5	

Figure 3: Model Scale Propeller

1.21 DUMMY MODEL WAKE SIMULATION

Due to the shortened dummy model and hence the incomplete boundary layer, the flow passing through the propeller plane is not the fully developed wake as in the general ship model. Therefore the construction of a wake screen is required to reproduce the same condition for the propeller in order to perform the propeller cavitation and noise test. As the wake data in full-scale ship is hard to measure, the wake measured by 5-hole Pitot tube in the towing tank of Istanbul Technical University (ITU) was used as the target wake.

For the current tests a Stereoscopic PIV wake survey was conducted to assist in constructing the grid. Each time a layer was added a survey was taken and the mesh altered. This time consuming process enabled good similarity between the target wake and the simulated wake.

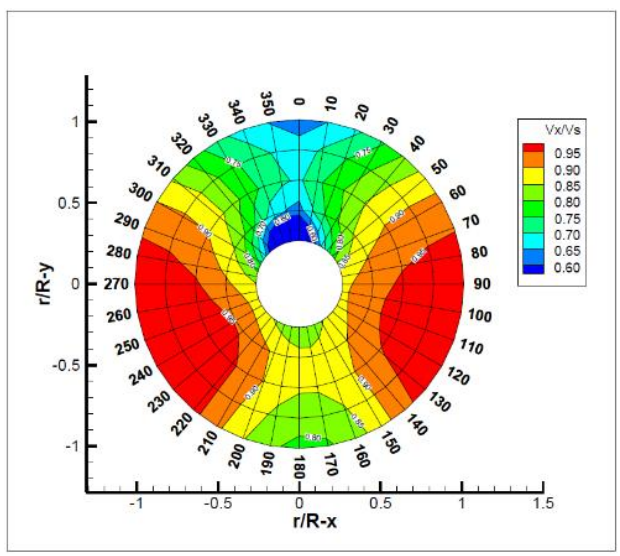

Figure 4: Target Wake from ITU Model Tests

It is important to note that as the test vessel was a catamaran, the wake distribution, unlike the dummy model, was not symmetrical. In order to test the most severe condition of the propeller, the left part of the target wake was chosen as the target, which is from 180 to 360 degrees.

Figure 5: Wake grid fitted to the model hull

1.3 TORQUE IDENTITY

The presence of the dummy hull in the cavitation tunnel causes a non-uniform inflow to the propeller. To compensate for this change in conditions the propeller test procedure must be modified to account for the faster flow through the propeller plane. Torque Identity simulation for the tunnel-tests was chosen since the full-scale measure torque was available. The exact full-scale condition is set when torque coefficient and cavitation number similarity are achieved.

For each condition an extra test was conducted, denoted by 'H'. During the tests the cavitation observations indicated that the cavitation extents for the corresponding run was less severe compared to the full-scale observations. Therefore for each run an additional run was made at a Heavily load condition. This was achieved by reducing the tunnel velocity so that 15% more torque was produced by the propeller without altering the rpm or cavitation number.

The reason for increasing the torque 15% was due to the fact that the area blockage ratio of the hull in the tunnel was approximately 15%. This means the set tunnel velocity will be roughly 15% higher when the tunnel water reaches to the propeller plane causing a reduction of the propeller loading. In other words, at full scale the vessel operates in a large volume of water in which the presence of the hull does not cause any velocity increase at the propeller. In the tunnel experiments the water was accelerated by the reduction in the measuring section cross sectional area due to the presence of the dummy hull.

1.4 PRINCESS ROYAL SET-UP

The cavitation observation set-up on The Princess Royal was different to most vessels in so far as it was considered early on in the design stage. The layout of the engine room was carefully monitored throughout this phase to ensure that there was minimal amount of interference with the measurement positions. The pressure taps and borescope ports were welded to the hull and the penetrations made during one of the refits. This type of measurement can be installed on existing vessels and it is something Class Societies such as Lloyds Register and ABS are extremely familiar with.

The portholes used for the observations however, required collaboration with the Class Society to meet their safety requirements to ensure the window did not fail. As the purpose of the window was photography using high-powered lighting, it became an important issue as the lights could damage or crack the glass. To this day there have been no such issues, the only difficulty with the system is the cleanliness of the glass, which can degrade depending upon the season. It is common for the porthole to be scrubbed for barnacles and slime prior to the sea trials by a diver. For one of the trials the barnacle secretion on the glass was particularly bad and affected the images but in general this method is simpler (once fitted) than the borescope to use, and you have the advantage of being able to see the propeller clearly with the naked eye. Figure 6 shows the aft demi-hull location of the windows near the rudder and Figure *7* shows the windows during dry-dock from outside of the vessel.

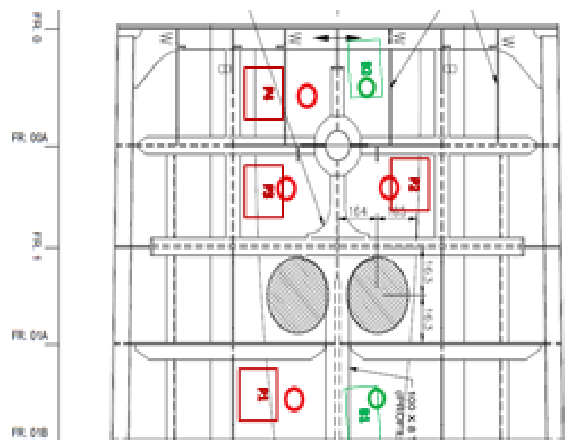

Figure 6 Full Scale window locations

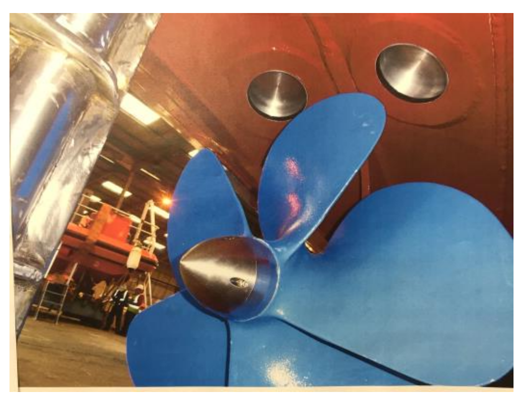

Figure 7: Portholes fitted for the camera observations

1.5 CAMERAS & PHOTOGRAPHY

Photographing propellers is a notoriously difficult pastime so a range of cameras were used in order to cover as many possibilities and opportunities to get good useful images. Table 4 gives the main cameras used in the experiment.

Table 4: Camera Specifications

Nano Sense MkII	5000 fps high speed video
Nano sense MkIII	1000 fps high speed video
Nikon D700 + 20mm f2.8 lens	6400 ASA giving 1/1000 sec at f 2.8 still images
Olympus Swing prism borescope with Pulnix camera	200 fps high speed video

Initially all the methods were benchmarked against one and other to assess their relative merits. As mentioned in Section 1.4, The Princess Royal was fitted with dedicated portholes over each propeller. The portholes allowed the propellers to be observed, videoed or photographed in a more conventional manner. As there was a pair of portholes, a light source and camera could exist quite comfortably in the confines of the engine room. Typically portholes are not an option on a vessel due to the installation and owners must rely on borescope techniques and available light to gather cavitation data on the propeller.

Borescope measurements on the vessel were made using dedicated housings for the probes and 20mm hull tappings, however the camera setup was problematic and the light intensity for the cameras could not be achieved very well so these were not used on the trials.

The Nanosense high-speed cameras worked extremely well with the porthole setup on the trials. The cameras were re-purposed from their usual PIV setup to be used with 35mm lenses through the portholes. The cameras were paired with a continuous high wattage light that had sufficient in built cooling to be used against the porthole glass for time domain shooting. In addition the cameras were also paired with the tunnel strobescope, which needed a trigger system to sync both camera and light source. This enabled better visualization of the cavitation with stroboscopic lighting and better understanding of the cavity dynamics under the continuous lighting.

The Nanosense cameras were eventually limited to the continuous light source as it gave better coverage of the cavity development. The strobescopes were triggered once per revolution so their values were effectively average pictures.

An additional set of experiments were performed whilst capturing videos and pressure synchronously in an effort to relate cavitation to measured pressure pulses. This has been achieved by connecting the high-speed cameras and the DAQ system to the signal generator, which helped filter out the signal from the motor shaft for triggering purposes.

Finally still images were taken with a full frame 35mm digital camera fitted with a distortion free 20mm f2.8 lens. This camera coupled with the high intensity light gave the best resolution images. The images were limited only by the narrow scatter possible with the light source and the lack of a timing trigger.

Once the sea trials data was complete the tests were replicated in the cavitation tunnel using the same test setup and lighting combinations. To keep the correlations consistent the continuous light source was again used with the high-speed cameras, supported by the still images. This is quite different from typical stroboscopic cavitation tunnel tests, but for this experiment it worked exceptionally well.

2 OPERATING AND TEST CONDITIONS

The testing conditions for cavitation tests in the Emerson Cavitation Tunnel has been determined by using the full scale trials that were conducted in September 2013.

To account for various environmental effects during the trials, the data sheets were carefully reviewed to finalize the test conditions to be simulated in the tunnel. Whilst making the final decision the running conditions with the most repetition were considered to be favourable in order to reduce the effect of current on vessel speed. In addition 1 non-cavitating condition and at least three cavitating conditions were found reasonable. An initial set of 4 running conditions were chosen, which included engine rpm values of 600, 900, 1200 and 2000. Even though it was not practical to use engine rpm as a reference for the running conditions, since one needs to know the gearbox ratio as complimentary information due to the inherent nature of full-scale trials, this value has been found as an easier configuration. The gearbox ratio of The Princess Royal of 1.75 was used to calculate the shaft rpm for the chosen runs. Additionally two other running conditions were also added namely 700 and 1500 engine rpm to cover the operating range with more tests. Table 5 presents the non-dimensional coefficients as well as some other significant parameters and recorded values. The values for delivered power, torque and shaft rpm are recorded from the port shaft. Table 6 presents the tunnel operating conditions.

3 FULL SCALE CAVITATION OBSERVATIONS

Detailed cavitation observations were undertaken in full-scale using three different cameras providing an understanding of the dynamics of the cavitation phenomena. *Figure 8* presents an image of the cavitation conditions during a run at a nominal engine speed of 1200 rpm recorded using a borescope. Figure 9 presents an image of cavitation at a higher vessel speed at 2000 rpm, again using a borescope. However owing to difficulties with the borescope windows mentioned previously, it was not possible to fully explore this otion on the trials.

Table 5: The Princess Royal Full Scale Conditions

Service Condition (% MCR)	2.2% MCR	6.9% MCR	16.1% MCR	73.4% MCR

Ship Speed [kt]	4.8	7.1	9.4	15.1
Engine rpm	600	900	1200	2000
Delivered Power (kW)	10.0	31.0	72.25	329.5
Propeller rpm	343	514	682	1142
Cavitation Number, σn	1.20	0.53	0.30	0.11
Torque (kNm) Full Scale	0.3	0.6	1.0	2.8
Torque ($10K_Q$)	0.378	0.336	0.318	0.318

Table 6: Model Scale Operating Conditions

Test	σ_N	rps	Hst mmHg	Torque (Nm)	V_T (m/s)
1	1.20	15	-254	3.84	1.39
2	0.54	20	-351	6.07	2.25
2H	0.54	20	-351	6.98	1.77
3	0.30	20	-510	5.75	2.41
3H	0.30	20	-510	6.61	1.96
4	0.11	30	-551	12.92	3.75
4H	0.11	30	-551	14.86	3.16
5	0.89	16	-328	4.30	1.44
5H	0.89	16	-328	4.94	0.97
6	0.19	25	-511	9.12	2.99
6H	0.19	25	-511	10.48	2.63

Figure 10 to Figure 18 present a series of still images of cavitation observations at engine speeds of between 600 to 2000 rpm taken using a Nikon D700 camera and continuous light source. The images are taken above and forward of the propeller blade looking aft and show a single propeller blade passing the observation window. The series shows the development of cavitation as vessel speed increases characterised by the lighter coloured region of bubbles developing on the propeller blade, which can also be seen trailing behind the vessel in some figures. These images represent a small selection of the still images and videos at various viewing angles and lighting conditions that were taken. They are also useful as they are in colour, helping to identify cavitation more precisely.

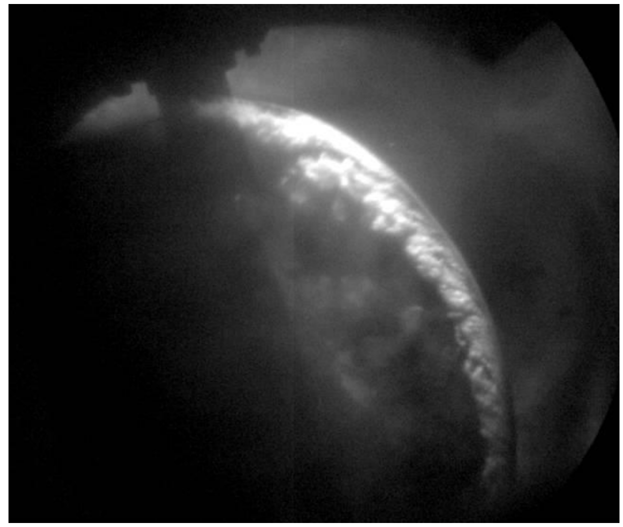

Figure 8: Full-scale cavitation observation at 1200 rpm using a borescope

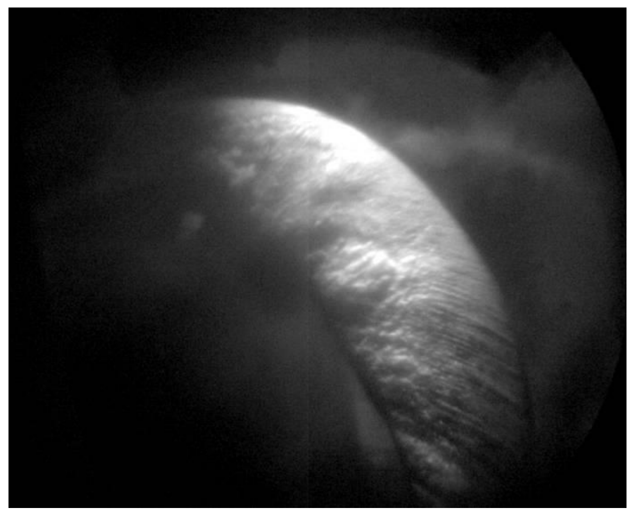

Figure 9: Full-scale cavitation observation at 2000 rpm using a borescope

Figure 10 shows the intermittent 'Leading Edge' (LE) Vortex Cavitation" was observed emanating from the suction side of the blade leading edges. Limited Starboard still pictures support that these vortices travel in the slipstream as weak "Trailing Tip Vortices".

Figure 11 shows less intermittent; rather continuous 'Leading edge Vortex Cavitation' emanates from the suction side of the blade and continues in the slipstream as trailing vortex extending to the rudder supported by the Starboard side pictures.

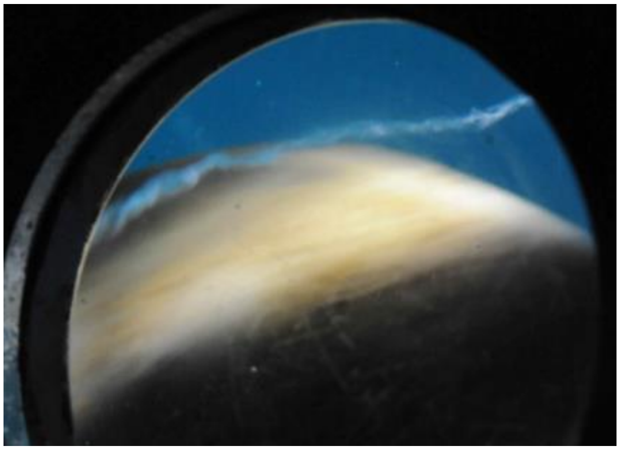

Figure 10: Full scale cavitation observation at 800 rpm

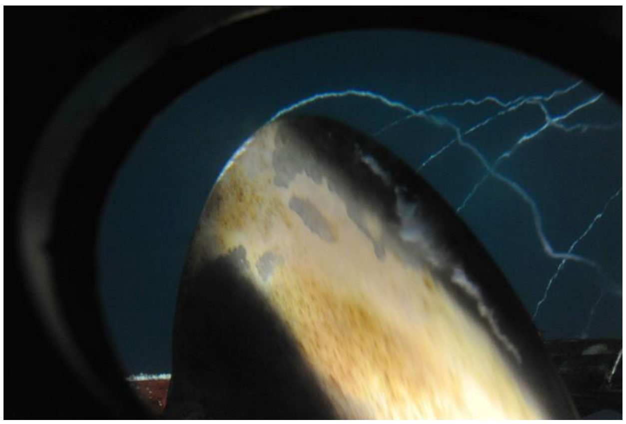

Figure 11 :Full scale cavitation observation at 900 rpm

Figure 12 shows the LE vortex cavitation is observed with rather steady and continuous nature (compared to the 900 rpm case). This is occasionally transformed to intermittent suction side "Sheet cavitation" developed in the form of a cluster of vortex streaks appearing at the blade LE. Very occasional appearance of "Hull-Propeller Vortex" developing between the propeller tip and observation window was observed. Starboard pictures confirm the continuation of the LE vortices as trailing tip vortices in the propeller's slipstream extending until rudder.

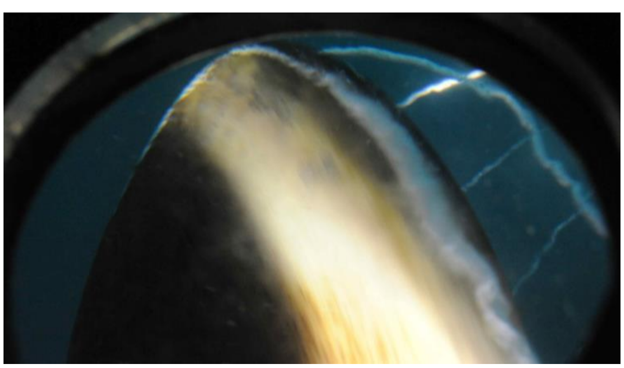

Figure 12: Full scale cavitation observation at 1000 rpm

Figure 13 shows the suction side "Sheet Cavitation" now is more dominant (compared to the 1000 rpm case) emanating from almost the entire blade LE. Its coverage is increasing from hub to tip. The sheet cavitation leaves the blade by rolling-up in the form of "Tip Vortex Cavitation" towards the trailing edge of the blade and travels in the slipstream. The Starboard side propeller pictures support the evidence of these trailing tip vortices extending to the rudder at the slipstream. Occasional appearance of intermittent "Hub Vortex" as well as intermittent "Hull-Propeller Vortex" cavitation is observed.

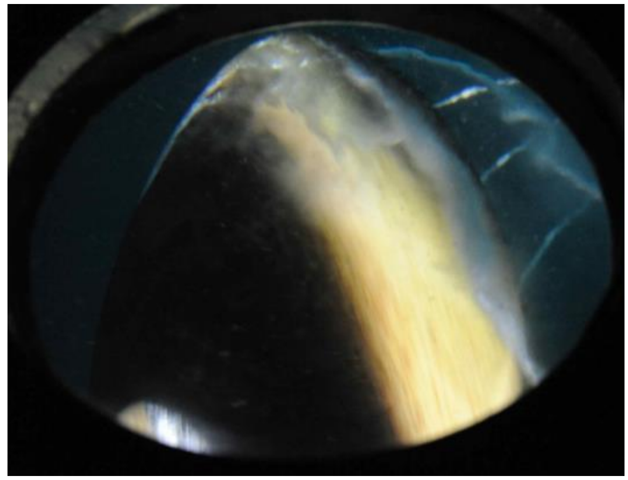

Figure 13: Full scale cavitation observation at 1100 rpm

Figure 14: Full scale cavitation observation at 1200 rpm

Figure 14 indicates a strong suction side "Sheet Cavitation" emanating from the entire blade leading edge with increased extent (hub to tip) terminates the blade by rolling-up in the form of "Trailing Tip Vortex" extending to the rudder. Partial "break-up of the sheet cavitation as well as occasional appearance of "Hub Vortex Cavitation" and "Hull-Propeller Vortex" cavitation are observed.

Figure 15 shows increased extent, volume and intensity of the suction side sheet cavitation (compared to the 1200 RPM case) is observed. This was unsteady with increased frequency of partial break-up's and cloudy appearance towards the tip. Supported by the Starboard side pictures, strong trailing tip vortices from each blade are observed extending to the rudder and bursting occasionally. Continuous Hub Vortex and very frequent Hull-Propeller Vortex Cavitation are also noted.

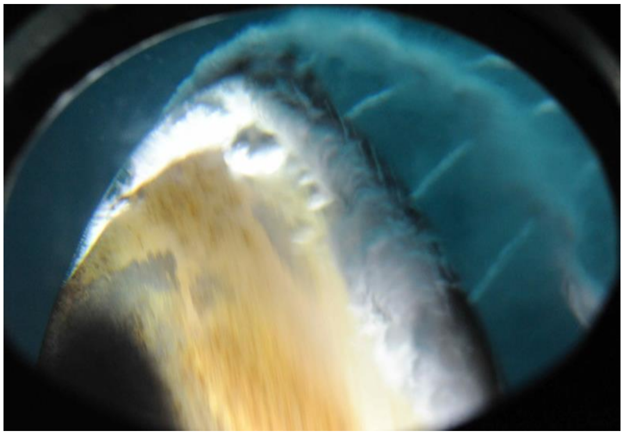

Figure 15: Full scale cavitation observation at 1300 rpm

In Figure 16 further increased extent, volume, intensity and unsteadiness of the suction side sheet cavitation are noted in comparison to the 1300 rpm case. This sheet cavitation terminates the blade at the tip region in the form of strong, twisted and cloudy trailing tip vortex extending to the rudder in the slipstream. Rather continuous Hub-Vortex cavitation and very often appearance of Hull-Propeller Cavitation are also noted.

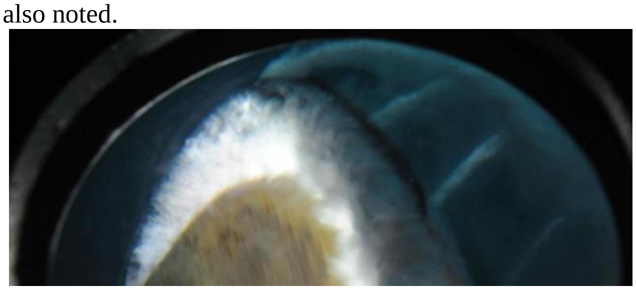

Figure 16: Full scale cavitation observation at 1400 rpm

In Figure 17 very unstable, increased extent, volume and intensity of cloudy Sheet Cavitation, compared to the 1400 rpm case was observed. The unsteadiness is more towards the blade tip where the sheet cavity terminates the blade by rolling-up and forming the increased strength and thickness of trailing Tip Vortex extending to the rudder. The trailing vortex breaks-up periodically into a cloud type of cavitation. Continuous and intensified Hub Vortex Cavitation as well as rather often developing Hull-Propeller Cavitation were noted.

In Figure 18 Large extent (almost 25-30% of the blade area), volume and intensity of the suction side sheet cavitation is observed. It is extremely unsteady, breaking-up (and bursting) time by time with cloudy appearance. This sheet cavitation terminates the blade at tip region by rolling-up, rather thick, intense and cloudy tip vortex trailing to the rudder. Time by time this trailing vortex bursts. The Hub-Vortex cavitation is much thicker, intense and continuous. The Hull-Propeller Vortex cavitation is very often develops with increased vortex diameter.

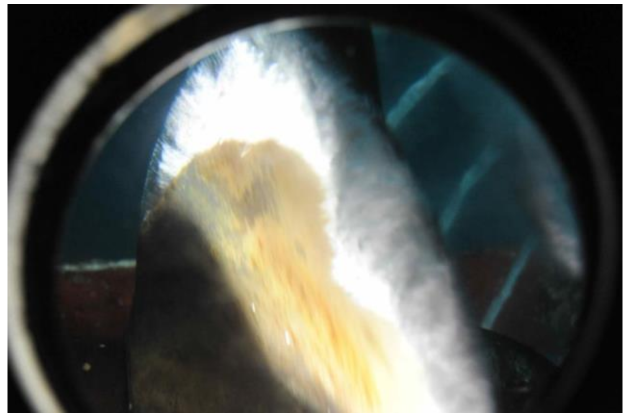

Figure 17: Full scale cavitation observation at 1500 rpm

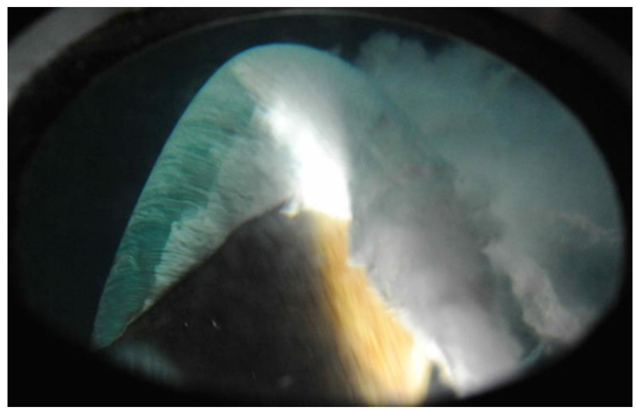

Figure 18: Full scale cavitation observation at 2000 rpm

HIGH SPEED VIDEO CAPTURES AND COMPARISONS WITH FULL SCALE

Figure 20 to Figure 24 show the observation in tunnel and the corresponding recording from full-scale trials. The figures are composed of images of the heavily loaded propeller in model scale and the full-scale observation. Three conditions are shown for 900, 1200 and 2000 rpm. From the images it is clear that The Princess Royal has sub-cavitating propellers with very low inception speed and strong tendency to develop cavitation with increasing propeller loading. During the full-scale trials, no cavitation was observed for the engine speed of 600 and 700 rpm respectively; this was also confirmed during the tunnel tests.

As the speed increased to 900 rpm shown in Figure 19 in full-scale, relatively continuous leading edge vortex emanating from the blade suction side and trailing in the slipstream up to rudder were observed. Figure 20 shows that this pattern was not fully supported in the tunnel measurements in terms of the strength of the cavitation pattern until the propeller loading was increased about 15% to simulate the same pattern with similar visual strength.

At 1200 rpm in full-scale a relatively strong suction side "Sheet Cavitation" emanating from the entire blade leading edge with increased extent (hub to tip) terminated the blade by rolling-up in the form of "Trailing Tip Vortex" extending to the rudder. In the tunnel tests the similar patterns could be observed in the heavily loaded condition while the normal corresponding condition displayed lesser extent of the cavitation observed in the full scale.

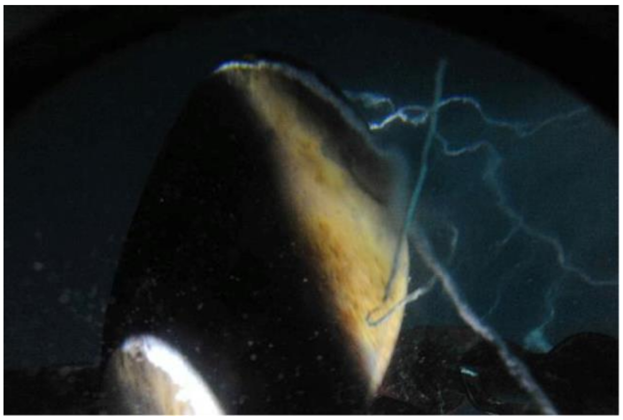

Figure 19: Full scale cavitation observation at 900 rpm

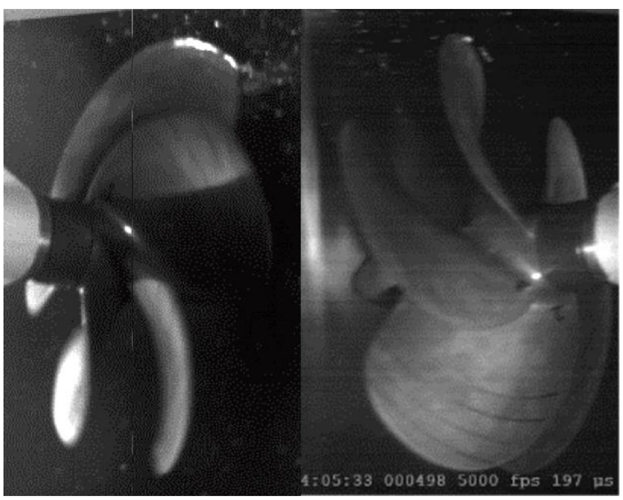

Figure 20: Cavitation Tunnel test of the propeller at equivalent 900 rpm full scale condition

With the engine speed of 2000 rpm was the closest to the Engine MCR (2300) condition and the full-scale propeller in this condition displayed rather large extent (almost 25-30% of the blade area), volume and intensity of the suction side sheet cavitation. As far as the comparison of the tunnel test observations with the full-scale cases was concerned there was a good correlation between the full-scale and model scale observations in terms of the types, strength and dynamic behaviour of the cavitation observed for the heavily loaded condition. The normal corresponding condition, yet again, simulated the similar patterns of the full-scale observations with reduced strength.

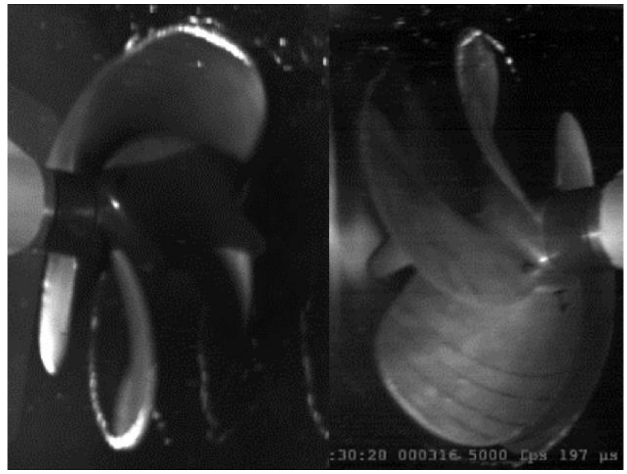

Figure 21: Cavitation Tunnel test of the propeller at equivalent 1200 rpm full scale condition

Figure 22: 1200 rpm full scale

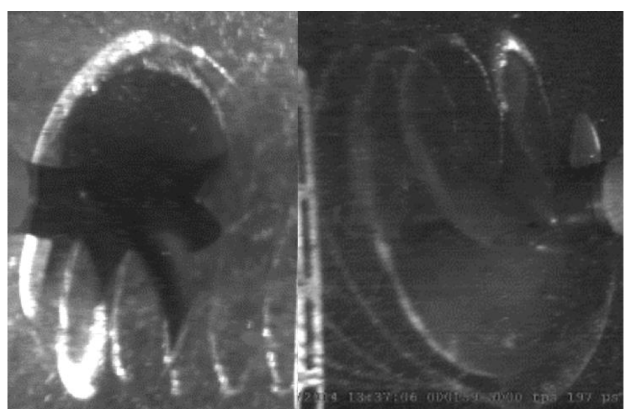

Figure 23: Cavitation Tunnel test of the propeller at equivalent 2000 rpm full scale condition

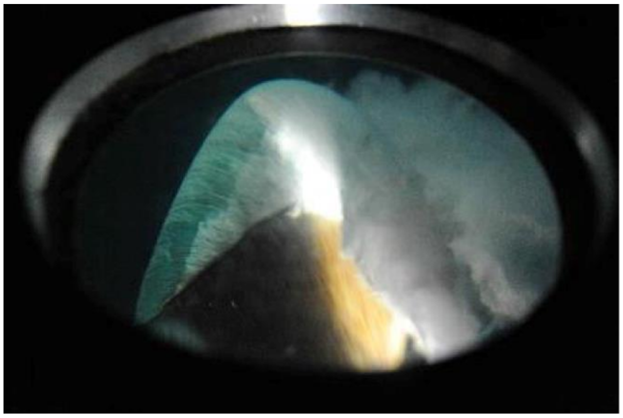

Figure 24:2000 rpm full scale

DISCUSSION

The results of the previous two sections show the great progress made in photographing ships propellers when in action. The art has moved from strapping cameras to the outside of vessels to borescopes, portholes and now high speed digital options.

The borescope system was hoped to be the default system for the research vessel. It provided a relatively low interference method, which could be used without the need for divers to clean portholes or obstruct valuable engine space. For the trials conducted in this report the borescope holder used to contain the viewing probe and manufactured locally, kept failing. This prevented the full exploitation of this device. In addition problems with the image intensifier and camera chosen limited the measurements to well lit intervals (sunlight) on sea trials.

One of the successes of the trials was the still images which were made possible by the large portholes. When the light was coupled with a high intensity light through the other porthole on the demi-hull, well lit and useful images were taken. The modern DSLR is able to increase the ASA / ISO rating to 3200 ASA without the grain normally associated with historically high film speeds. The limit for the current setup was the light source. The high intensity light has a condensing lens fitted allowing it to be focused, the field of view for the light projected from the source was narrow so only sections of the propeller were lit. A better solution would have been a ring flash fitted in front of the lens allowing near contact with the glass and plenty of light to illuminate the blade.

The default video method became the high speed video system. Initially powered by the stroboscope the continuous light source soon became a permanent fit for the high speed camera and many hours of high speed video were recorded showing the growth and collapse of the cavitation cavities. The system was relatively bulky requiring some specialist clamps to hold the camera and light source but the acquired images show how successful the system was. Again the system could benefit from a wider light source or multiple light sources to light the propeller better together with an option for a colour high-speed system. With miniaturisation of the components this system will only reduce in size and cost and increase in quality in the future.

CONCLUSIONS

The full scale / model scale cavitation observations performed as part of the SONIC project were a great success. From the results the following conclusions were reached:

- It is possible to replicate the photographic set-up between full scale and model scale cavitation tests with a good level of success.

- There was a good correlation between the full-scale and model scale observations in terms of the types, strength and dynamic behaviour of the cavitation observed for the heavily loaded condition.

- The high-speed cameras were sufficiently sensitive to record a high frame rate of propeller cavitation and help understand the full scale cavity dynamics better.

- The clearest and most detailed photos were recorded using a digital still camera

- The borescope is the most commercially viable method of conducting these experiments however the image quality may be a challenge for cavitation research.

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